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EFFECT OF (MGO) NANOFLUID ON HEAT TRANSFER CHARACTERISTICS FOR INTEGRAL FINNED TUBE HEAT EXCHANGER

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ABSTRACT

Experimental investigations have been carried out in this paper to study the enhancement of heat transfer characteristics for cross flow low integral finned tube heat exchanger with using of (MgO) nanofluid. The study includes designing and manufacturing of test section from Pyrex glass with dimensions (250×500×1200) mm width, height and length, respectively. has a single copper tube with eight passes.. The low integral finned tube with (19 mm) inner diameter, (21 mm) root diameter and (24 mm) outer diameter. The fin height is (1.5 mm), thickness (1 mm) and the pitch is (2 mm). Air was used as a cooling fluid passing across the test tube with a range of velocities (1, 2, 3 and 4) m/sec. The inner side flow rates with a range of (2, 3, 4, 5 and 6) L/min. for water and for nanofluid. The fluid temperatures at the inlet of test tube were (50, 60, 70, 80) °C. Magnesium Oxide (MgO) nanoparticle powder with (40 nm) diameter was dispersed in distilled water with different volume concentrations (0.15, 0.35, 0.55, and 0.75) % by volume is used to prepare the nanofluid. The results showed increasing of thermal conductivity and density of fluid when using nanofluid, the results also showed enhancement of heat transfer characteristics when using the nanofluid.

GENERAL TERMS

*Ai: inner surface area of tube (m^2), Ao: outer surface area of tube (m^2),*Cp:*, Specific heat of the fluid (J/kg.°C), d: tube diameter (m), hi: inner side heat transfer coefficient (W/m^2.°C),* Re_a*: air side Reynolds number, ho: air side heat transfer coefficient (W/m^2.°C), ho_f: air side heat transfer coefficient for finned tube (W/m^2.°C), ho_s: air side heat transfer coefficient for smooth tube (W/m^2.°C) K: thermal conductivity of tube material (W/m.°C), K_{nf}: thermal conductivity of nanofluid (W/m.°C), K_w: thermal conductivity of water (W/m.°C), L: length of tube (m).,* Nu_a*: air side Nesselt number,* Nu_{nf}*: Nesselt number of nanofluid,*Nu_w*: Nesselt number of water, Q: heat transfer rate (Watt), R: thermal resistance,* Re_{nf}*: Reynolds number of nanofluid,* Re_w*: Reynolds number of water, T: temperature (°C), Ts: surface temperature (°C), Tm: mean temperature (°C), Ui: inner side overall heat transfer coefficient (W/m^2.°C), Uo: air side overall heat transfer coefficient (W/m^2.°C),),* u_w *: velocity of water (m/s),* $\dot{m}$*: mass flow rate (kg/s), ΔT: temperature difference (°C),* ρ_{nf} *: density of nanofluid* ρ_w *: density of water (Kg/m^3)* μ_{nf} *: visocity of nanofluid (kg/m.s),* μ_w *: visocity of water (kg/m.s).φ : volume fraction of nanoparticles.*

Keywords: Nanofluid, Nanoparticles, Integral Fin, Heat Transfer Coefficient, Enhancement.

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1. INTRODUCTION

Nanofluid is one of the nanotechnology applications which created by suspensions of nanoparticles (1-100) nm of high thermal conductivity materials into base fluid (water, oil) to improve the overall thermal conductivity and the convective heat transfer characteristics of the base fluid. Nanoparticles shapes are spherical or cylindrical**.** The advantages of nanofluid are:[1]Higher thermal conductivity, excellent stability, little penalty due to an increase in pressure drop and little damage in pipe wall due to increase of suspensions nanoparticles abrasion.

Nanofluid appears to be a very remarkable and new heat transfer fluid, it's used to enhance the heat transfer rate for many thermal systems. One process of the following are used to prepared the nanoparticles: [1]

- Physical processes: this process including mechanical grinding and condensation of the inert gas.
- Chemical processes: this process including chemical precipitation of the particles, spray pyrolysis, and thermal sterilizing.

Xuan and Li (2003), [2] deliberated the heat transfer for turbulent flow of nanofluid inside a tube. They investigated Cu-water nanofluid in a (10 mm) inner diameter straight brass tube with (800 mm) length. They establish that, the heat transfer coefficient of nanofluids containing 2% Cu nanoparticles was enhanced by 40% with associated to that of water. They predicted a correlation for turbulent flow of nanofluid to calculate Nusselt number inside a tube which are:

$$Nu_{nf} = 0.0059(1 + 7.6286\, \varphi^{0.6886}\, Pe_d)^{0.001}\, {Re_{nf}}^{0.9238}\, {Pr_{nf}}^{0.4}$$

Khalid (2012), [3] performed an experimental and theoretical study to investigate heat transfer and flow for nanofluid in a horizontal and an inclined circular tube heated by a uniform axial heat flux, flow laminar. Using three types of nanofluid, Al (25nm), CuO (50nm) and Al_2O_3 (30nm). The values of (NuR) were estimated to be [45%, 31% and 25%] for (Al, Al_2O_3 and CuO) nanofluid, with the uniform heat flux and (36%, 27% and 22%) constant wall temperature.

Firas (2014), [4] performed an experimental and numerical investigation for heat exchanger with U-longitudinal finned tube to study its performance with water and with nanofluid. (Al_2O_3 andTiO_2) nanoparticles with nano concentrations (0.2%, 0.4%, 0.6% and 0.8%) were used to prepare nanofluid. For experimental results with nanofluid, the convective heat transfer coefficient was increased with increasing of both Reynold's number and nano concentration. At (0.8%) volume concentration, the heat transfer coefficient increase by (21%) and thermal conductivity increased by (5%), when using (Al_2O_3) nanofluid. Also, the heat transfer coefficient increase by (16%) and thermal conductivity increased by (4.4%), when using (TiO_2) nanofluid.

Asmaa, et al (2015)[5].studied experimentally the enhancements of heat transfer coefficient and Nusselt number in a heat exchanger system by using Titanium-dioxide (TiO_2) nanoparticles with an average diameter of (10 nanometer), experimental results show that the Nusselt number increased by (17%) as with respect to water at a (0.0192) m/s nanofluid velocity at inlet temperature of (60) ^{o}C.

2. NANOFLUID PREPARATION METHODS

Two methods are used for prepared nanofluid which are: [6]

2.1 Single-Step Method

This method is include preparation of nanoparticles combining and synthesis of nanofluid, nanoparticles are prepared by Physical or chemical process. In this method, dispersion of nanoparticles, drying, storage and transportation are avoided, therefore, nanoparticles agglomeration is minimized and fluids stability is increased. However, this method used only for low vapor pressure fluids.

2.2 Two-Step Method

The nanoparticles are manufacture as a powder by some suitable techniques in this method, then dispersing the nanopowder the base fluid. In both steps of this method, there's agglomeration of nanoparticles during nanoparticles storage and transportation. Simple techniques used to decrease particle aggregation and improve dispersion behavior such as ultrasonic agitation. Since several companies adopted the nano powder synthesis techniques, so, the two-step synthesis method are economically advantageous. In this study, the second method is used.

3. NANOPARTICLES AND BASE FLUID

In the present study, Magnesium oxide nanoparticles (MgO) are utilized. Table (3.1) shows the specification of (MgO) nanoparticles. [7]. The base fluid used is distilled water.

Table 3.1 Specification of (MgO) nanoparticles

Nanoparticle	Mean diameter (nm)	Density kg/m^3	Thermal conductivity W/m. °C	Specific heat J/kg.°C
MgO	40	3580	48.4	877

4. OBJECTIVES OF THE RESEARCH

4.1. The Aims

This study aims to enhance the heat transfer characteristics for heat exchanger with use of nanofluid as a working substance.

4.2. The Scope

Design the test loop cross flow heat exchanger to obtain the flow and heat transfer characteristics, manufacture conformal test section from Pyrex with low integral finned tube, investigate the effect of using (MgO) nanofluid instead of hot water on heat transfer characteristics for integral low finned tube, study the average surface temperature by using the thermal imager, data analysis and quantification of complete measuring process, develop empirical correlation for Nusselt number for air side of low integral finned tube as function of Reynold's number, Prandtl's number and empirical correlations for hot water and nanofluid.

5. THEORITICAL EQUATIONS

5.1 Heat Exchanger Analysis

The heat disspation rate: [8]

$$Q = \dot{m}_h C_{ph}(T_{hi} - T_{ho}) = \dot{m}_c C_{pc}(T_{co} - T_{ci}) \qquad 5.1$$

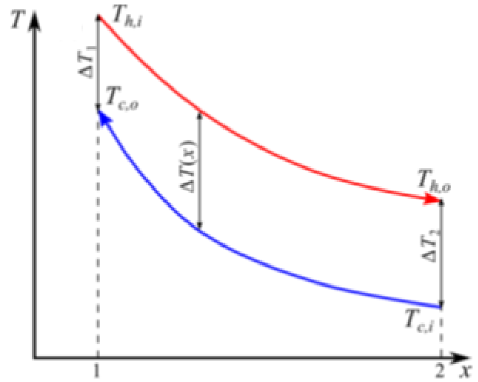

Figure 1 Temperature profiles in a counter-flow.

Logarithmic mean temperature difference is estimate from the relation [9]:

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\Delta T_1 / \Delta T_2\right)} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\Delta T_2 / \Delta T_1\right)} \qquad 5.2$$

$\Delta T_m = F.LMTD$

here, F ≈ 0.999

The overall heat transfer coefficient is a reciprocal of total thermal resistance of two fluids separated by a wall. [10].

$$R_{total} = R_o + R_{wall} + R_i \qquad 5.3$$

$$R_{total} = \frac{1}{h_o A_o} + \frac{ln(^{d_o}/_{d_i})}{2\pi KL} + \frac{1}{h_i A_i} \qquad 5.4$$

$$Q = \frac{\Delta T_m}{R_{total}} = UA\Delta T_m = U_i A_i \Delta T_m = U_o A_o \Delta T_m \qquad 5.5$$

$$UA = \frac{1}{\frac{1}{h_o A_o} + \frac{ln(^{d_o}/_{d_i})}{2\pi KL} + \frac{1}{h_i A_i}} \qquad 5.6$$

The average surface temperature is calculated according to expression:

$$T_s = \frac{T_1 + T_2 + T_3 + \cdots + T_n}{n} \qquad 5.7$$

Inner side heat transfer coefficient (water or nanofluid):[11]

$$h_i = \frac{Q}{A_i \times (T_m - T_s)} \qquad 5.8$$

$$T_m = \frac{(T_{hi} + T_{ho})}{2} \qquad 5.9$$

Then, the inner side Nusslte's number can be calculated as follows:

$$Nu_w = \frac{h_i \times d_i}{K_w} \qquad 3.28$$

For flow of nanofluid inside a tube

$$Nu_{nf} = \frac{h_i \times d_i}{K_{nf}} \qquad 3.31$$

For low integral finned tube

$$h_o = \frac{1}{\frac{1}{U_o} - \frac{d_o \, ln\left(^{d_r}/_{d_i}\right)}{2K} - \frac{d_o}{h_i d_i}} \qquad 3.35$$

$$Re_a = \frac{\rho_a \, u_a \, d_h}{\mu_a} \qquad 3.36$$

$$d_h = \frac{4 \times cross\ sectional\ area\ of\ the\ air\ duct}{perimeter\ of\ the\ air\ duct} \qquad 3.37$$

Prandtle number for air side of tube:

$$Pr_a = \frac{\mu_a \, Cp_a}{K_a} \qquad 3.41$$

Nusslte number for air side:

$$Nu_a = \frac{h_o\, d_o}{K_a} \qquad 3.42$$

Percentage of enhancement:

$$h_o\,\% = \frac{h_{o\,nf} - h_{o\,w}}{h_{o\,w}} \times 100 \qquad 3.48$$

5.2. Thermo-physical Properties of Nanofluid.

5.2.1. Volume Fraction.

The volume fraction (φ) is the percentage of volume of nanoparticles to the mixture volume of base fluid (water) with nanoparticles.

$$\varphi = \frac{\langle \frac{W_p}{\rho_p} \rangle}{\langle \frac{W_b}{\rho_b} + \frac{W_p}{\rho_p} \rangle} \times 100 \qquad 3.49$$

5.2.2. Thermal Conductivity

Many semi empirical correlations were reported to calculate the nanofluid effective thermal conductivity, Maxwell formulated the following expression. [14].

$$\frac{K_{nf}}{K_b} = \frac{K_p + 2K_b - 2(K_b - K_p)\varphi}{K_p + 2K_b + (K_b - K_p)\varphi} \qquad 3.50$$

5.2.3 Density.

The nanofluid density is calculated by (**Pak** and **Cho)** correlations, [15]

$$\rho_{nf} = (1 - \varphi)\rho_b + \varphi\rho_p \qquad 3.51$$

5.2.4. Specific Heat

The specific heat is calculated from **Xuan** and **Roetzel** as following, [16].

$$(C_p)_{nf} = (1 - \varphi)(C_p)_b + \varphi(C_p)_p \qquad 3.52$$

5.2.5 Viscosity

The viscosity of the nanofluid can be calculated using the **Drew** and **Passman** relation, [17]

$$\mu_{nf} = (1 + 2.5\varphi)\mu_b \qquad 3.53$$

6. EXPERIMENTAL SET UP

6.1. Preparation of (MgO) Nanofluid

The process of preparation of stable nanofluid with no agglomeration is the first step in the experimental procedure which uses the nanofluid in heat transfer enhancement. Nanoparticle that is using to preparation of nanofluid is expensive in price and dangerous in treatment. Two-step method is used in preparation of nanofluid in present work. This method requires produce nanoparticle, then the ultrasonic vibration homogenizer device is used for mixing with the base fluid. The ultrasonic device was filled with water to make sure no damage will happen to the device as recommended by the instructions of the supplier, and then the basket was put inside the bath. (MgO)

nanoparticles are mixed with distilled water after weighting it by electronic balance. A (3) liters of distilled water are used in all volume concentration. Four volume concentrations of (MgO) nanofluid have been used in this study are shown with weights in table (6.1). The ultrasonic vibration homogenizer device is shown in figure (2).

Table 6.1 Weight of (MgO) nanoparticles with volume concentrations

Volume Concentrations (%)	0.15	0.35	0.55	0.75
Weight of (MgO) powder (grams)	16.33	38.18	60.12	82.14

Figure 2 Photograph of ultrasonic vibration homogenizer device.

6.2. Test section

The experimental work includes designing and manufacturing of test section from Pyrex glass, with rectangular cross section with the dimensions (250×500×1200) mm width, height and length, respectively, figure (3) show a photograph of test tube. The test section has an integral low finned copper tube of (8) passes with (19, 21, 24) mm inner, root and outer diameters respectively. The height of fin's is (1.5 mm) with a thickness of (1 mm) and pitch (2 mm) A plane of test tube is shown in figure (3), lathe machine were used to manufacture the finned tubes.

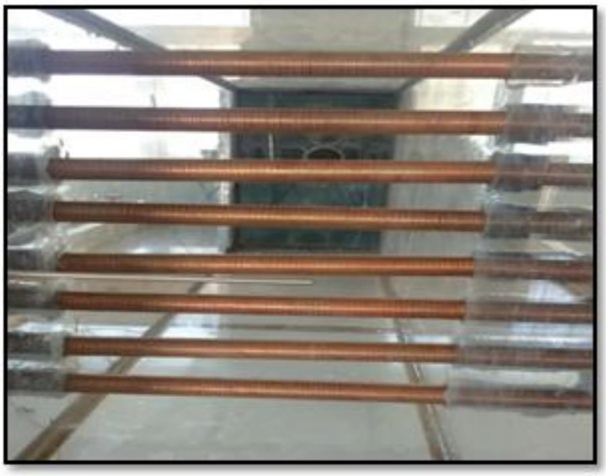

Figure 3 photograph of test tube.

6.3. Experimental Test Rig Specification

The air flow system consists of centrifugal blower to deliver the air to the test section, diffuser and air duct is manufactured by a galvanized steel used to supply the air to test section. The water or nanofluid loop system consist of a pump used for pushing the hot fluid to the test tube, Heater to supply hot fluid and an insulated tank of dimensions (200x200x400) very well insulated by glass wool, the tank is used circulate hot water Figure (4) shows photograph of experimental test rig. and figure (5) shows a schematic diagram of fluid loop system.

Figure 4 Photograph of experimental test rig

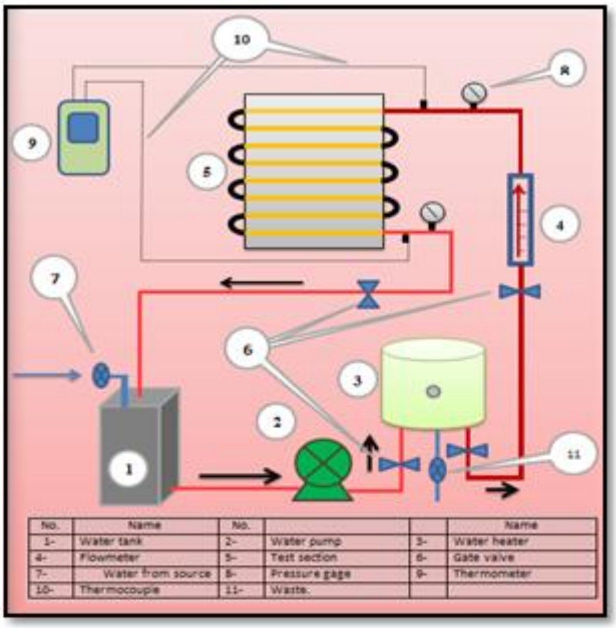

Figure 5 Schematic diagram of fluid loop system**.**

6.4. Measurement Devices

The temperature measuring device used in the present work are:

A four- channel temperature recorder, two thermocouples type (K) (-100 to 1300) °C are immersed the inlet and outlet of the test tube are used to measure the temperature of hot fluid at these locations and two temperature probes of (K-type, Ni Cr–Ni Al) having a temperature range of (0 - 800) °C are used for measuring the air temperature at the inlet and outlet of test section.

The other measurement devices are:

[hot-Wire anemometer, flow meter, thermometer, pressure gauges, and thermal imager].

6.5. Uncertainty Analysis

The experimental uncertainties must be given proper attention in the experimental research, The method proposed by Kline and McClintock [18] seems to be widely accepted among the authors of technical papers. The maximum measurement uncertainties were: heat dissipation rate (-6.98% to 7.61%) , inner side Reynold's number (-3.41% to 1.47%), inner side heat transfer coefficient (-9.25% to 15.31%), air side Reynold's number (-5.07% to 7.92%) and air side heat transfer coefficient (-7.46% to 7.24%).

7. RESULTS AND DISCUSIONS

Figures (6, 7, 8 and 9) show properties after adding nanoparticles with concentrations of (0.15%, 0.35%, 0.55%, 0.75%) to the distilled water. The thermal conductivity is the most important property, therefore, figure (6) shows increasing the thermal conductivity by increased the concentration of nanoparticles, the maximum increase is (2.17%) with volume fraction of (0.75%). The density increases by increasing volume fraction as shown in figure (7), the maximum increment in density is about (2%) at volume fraction of (0.75 %). Figure (8) shows decreasing of the specific heat with increasing the concentration of nanoparticles, maximum decrement is about (0.59%). The viscosity is increased by increasing the concentration of nanoparticles as shown in figure (9).

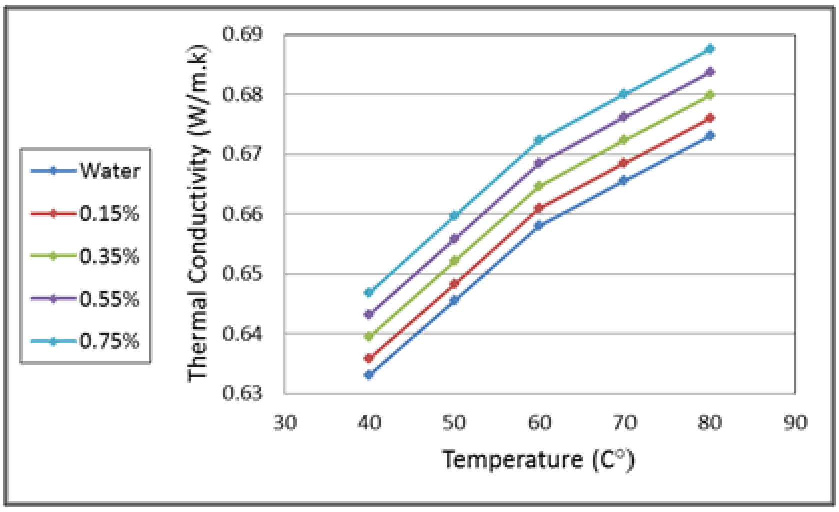

Figure 6 The effect of nano volume concentration on the fluid thermal conductivity

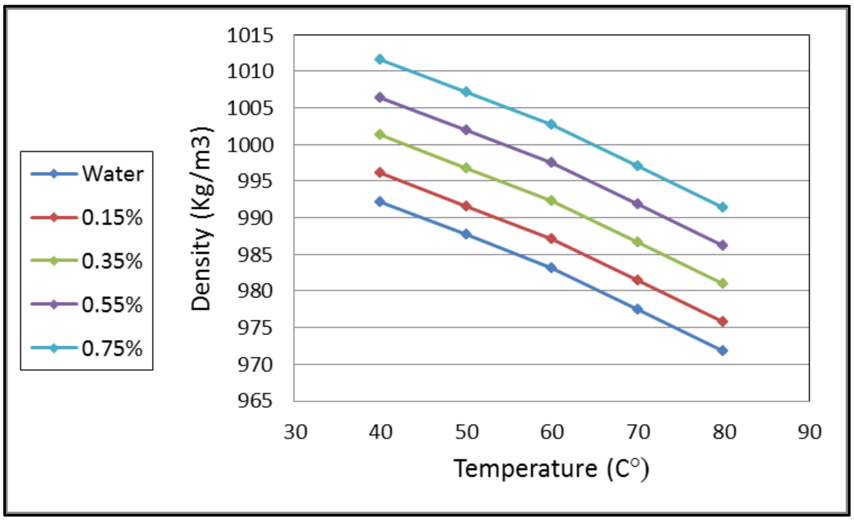

Figure 6 The effect of nano volume concentration on the fluid thermal conductivity.

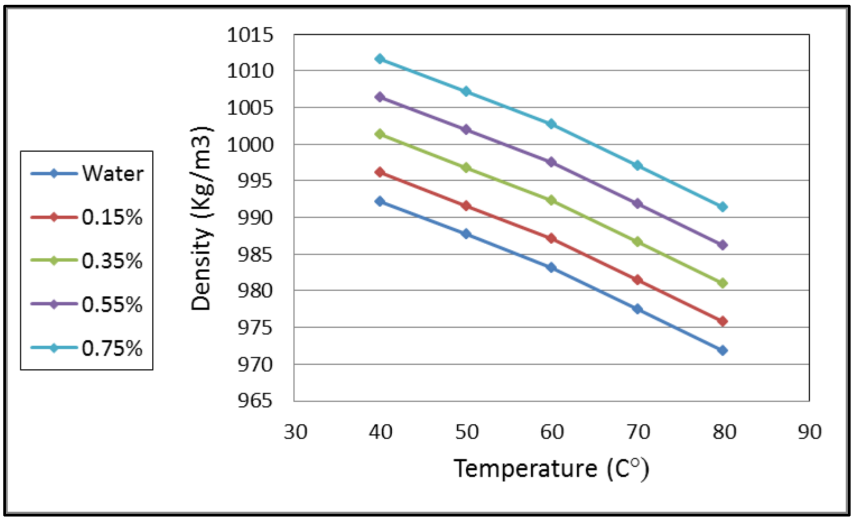

Figure 7 The effect of nano volume concentration on the fluid dencity.

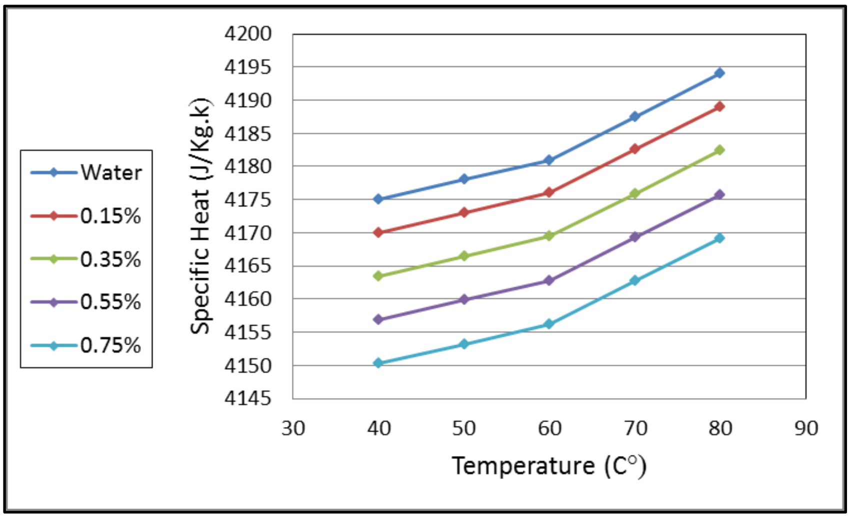

Figure 8 The effect of nano volume concentration on the fluid specific heat.

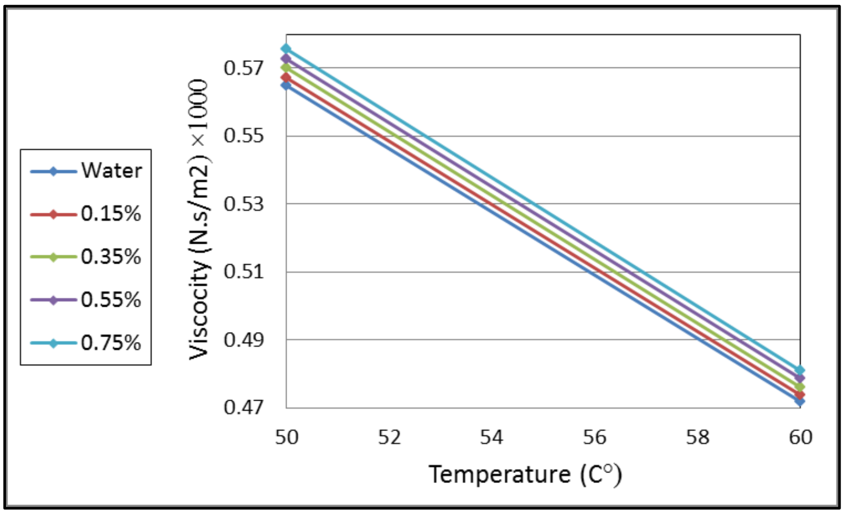

Figure 9 The effect of nano volume concentration on the fluid viscocity.

Figure (10) clarify the variation of heat dissipation rate with water and different nano concentration for integral finned tube at different inlet temperatures, air velocities and flow rates. It's clear from these figures increasing of heat dissipation rate with increasing of (MgO) nanoparticles in the nanofluid at similar boundary conditions. The maximum enhancement was (15.85%) occurs at nano concentration of (0.75%).

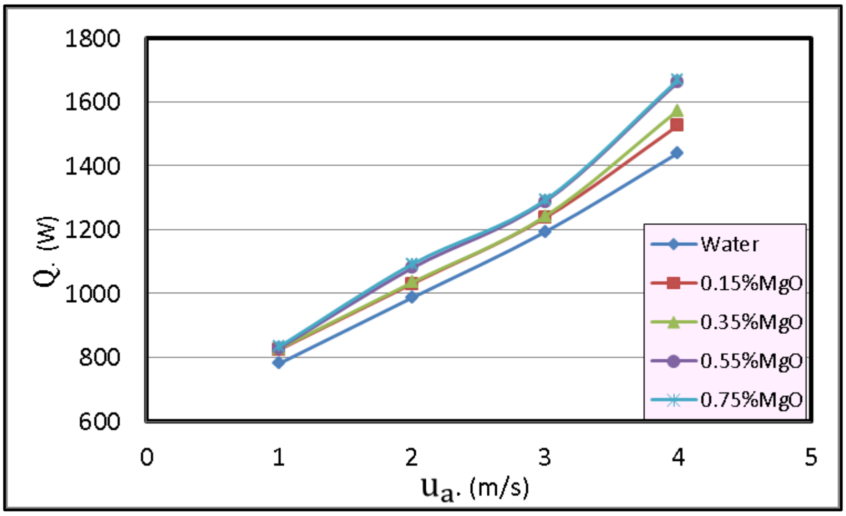

Figure 10 Variation of heat dissipation rate with water and different nano concentration

Figure (11) reveal the variation of air side heat transfer coefficient with water and different nano concentration for integral finned tube at different inlet temperatures, air velocities and flow rates. These figures present the increasing of air side heat transfer coefficient (ho) with increasing of (MgO) nanoparticles in the water at similar boundary conditions. The maximum enhancement of Magnesium Oxide nanofluid was (19.23%) over the use of water.

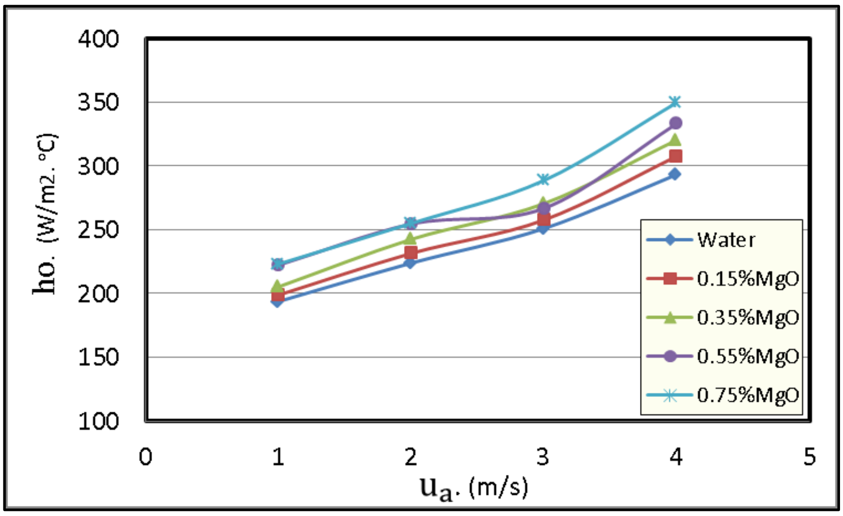

Figure 11 Variation of air side heat transfer coefficient with water and different nano concentration

Figure (12) show the variation of air side Nusselt's number with water and different nano concentration for integral finned tube at different inlet temperatures, air velocities and flow rates. These figures reveal the increasing of air side Nusselt's number (Nua) with increasing of (MgO) nanoparticles in the water at similar boundary conditions. Magnesium Oxide nanofluid makes a maximum enhancement of (16.31%) over the water.

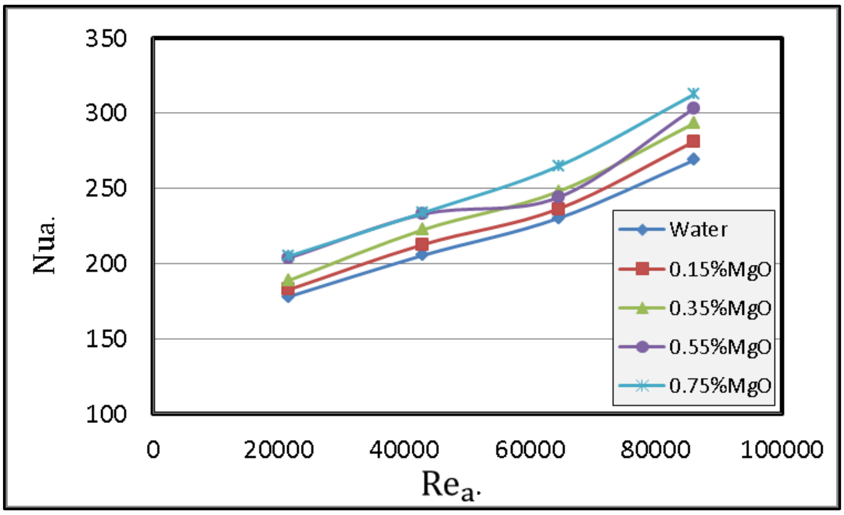

Figure 12 Variation of air side Nusselt's number with water and different nano concentrations

8. CONCLUSIONS

The following comments could be concluded:-

- The heat dissipation rate (Q) are increase with the increase of nanoparticle concentration in the water, the maximum percentage of enhancement was (15.85%) over the base fluid, occurs at (0.75%) nanoparticle concentration.
- The air side heat transfer coefficient are increase with the increase of nanoparticle concentration in the base fluid, for finned tube with nanofluid, The maximum percentage of enhancement was (19.23%) over the base fluid, occurs at (0.75%) nanoparticle concentration.

- The air side Nusselt's number are increase with the increase of nanoparticle concentration in the base fluid, The maximum percentage of enhancement was (16.31%) over the base fluid, occurs at (0.75%) nanoparticle concentration
- Increasing the nanoparticle concentration in the nanofluid have a substantial effect on enhancement of thermal conductivity and heat transfer coefficient, at the same time, it's increasing the density and viscosity, whereas decreasing the specific heat.

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